VERTICAL STRUCTURE OF THE INHERENT OPTICAL PROPERTIES

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LONG-TERM GOALS

The long-term goal of this project is to be able to predict the three-dimensional structure of the light absorption, scattering, and attenuation properties of the ocean (Inherent Optical Properties, IOP) based on physical and biogeochemical forcing functions.

OBJECTIVES

The main objective of this year's effort is to expand our understanding of the inherent optical properties in coastal to littoral environments via theoretical studies, observations, and analysis. A second objective is to develop new inversion algorithms to describe the IOP from physical features evident from the variability in the upwelling light field.

APPROACH

The approach to the overall objective of the prediction of IOP in the marine environment is to use a feedback loop between theoretical work, *in situ* measurements, and instrument development. For example recent instrument development efforts at O.S.U. and Western Environmental Technologies Laboratories (WET Labs) have made it possible to routinely measure the spectral absorption, scattering, and attenuation properties of the ocean. It is now possible to maintain calibration between cruises by means of reference to pure water.

These experimental procedures have led to a global data set of IOP that can be used to study global similarities and regional differences. These global similarities and regional differences in turn have led to hypotheses regarding the structure of the light field in the

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upper ocean in response to micro-bubble and turbulence, inversion algorithms to obtain IOP from remote sensing, and the fundamental behavior of light absorption in relation to temperature and salinity.

Theoretical work is carried out primarily by Dr. J. R. V. Zaneveld. The observational program is carried out under the direction of Dr. W. S. Pegau. Mr. A. H. Barnard is in charge of image and data analysis. Two post-doctoral students, Dr. Darek Bogucki and Dr. Anne Petrenko, are also partially supported by this program. Dr. Bogucki is studying the relationship between oceanic turbulence and light scattering. Dr. Petrenko is studying the effects of thin layers on the radiative transfer in the upper ocean.

WORK COMPLETED

We have assembled a SLOW Descent Rate Optical Platform (SLOWDROP) which contains multiple devices for the *in situ* measurement of total spectral IOP, dissolved material IOP (and particulate IOP by difference), spectral fluorescence, CTD, and most recently the spectral volume scattering function at intermediate and large angles. The platform continues to evolve as instruments become available.

We have described our inversion theory for the determination of physical features from optical remote sensing of fronts, thin layers and internal waves (Zaneveld and Pegau, 1997). In a cooperative effort with Dr. P. Flatau of Scripps, we have been studying the potential influence of micro-bubbles on the radiative transfer (reflectance; average cosine) in the upper ocean (Flatau, et. al., 1997). We have studied the potential influence of turbulence on light scattering (Bogucki, et. al., 1997).

We have described the relationship between spectral absorption, scattering, and attenuation coefficients based on our global IOP data set (Barnard, et. al., 1997).

We have established the dependence of the absorption coefficient of pure ocean water on temperature and salinity (Pegau, et. al., 1997).

We participated in two planning meetings for the “Thin Layers” project, one at the Ocean Sciences meeting in Santa Fe, NM in February 1997, and one in August 1997 in Corvallis, OR.

In September 1997 we participated in a research cruise off the Oregon Coast for the purpose of obtaining data for the study of inversions using the recently launched SeaWiFS ocean color satellite sensor.

RESULTS

The results from a two-flow radiative transfer model study showed that physical features such as thin layers, fronts, and internal waves can be delineated from the remotely sensed reflectance when the backscattering and absorption properties of the water do not covary

(Zaneveld and Pegau, 1997). In such systems the reflectance at the front and away from the front is different due to differences in the optical properties, and thus can be used to determine the slope of the front. The wavelength and in some cases the amplitude of internal waves can be determined if the internal wave displaces an optical layer. In the case where the optical properties are covarying, the two-layered system can be replaced by an equivalent homogeneous system.

An ongoing study of the relationship between the diffuse attenuation coefficient and the absorption coefficient has shown closure between the IOP and apparent optical properties (AOP) in the blue portion of the visible spectrum (Zaneveld et. al., 1996). This study indicates that the light field in the surface zone appears to be more diffuse from that predicted by theory. The average cosine, however, is well modeled using an asymptotic approximation. The results show that the asymptotic approximation of the diffuse attenuation coefficient can be accurately predicted from the IOP at blue wavelengths. These results have led to our working with Dr. Flatau of Scripps to numerically model the effects of bubbles on the light field (Flatau et al., 1997). Results from this study show that scattering caused by small bubbles near the surface can rapidly diffuse the light field. Bubbles thus provide a mechanism to diffuse the light field to near the asymptotic conditions, which could explain the empirical relations, found between the diffuse attenuation and absorption coefficients. The study of Bogucki, et. al. (1996; 1997) found that in strong turbulent coastal regions, the scattering effects of turbulent inhomogeneities of the seawater can dominate over the particulate scattering, thereby reducing the visibility.

The theory of our backscattering independent absorption algorithm is present briefly. The basis of this work focuses on the classical wavelength dependencies for water and particulate matter (i.e. $\lambda^{-4.3}$ and λ^{-n}). Over realistic ocean ranges, the fraction $b_b(\lambda_2)^2$ / $[b_b(\lambda_1)\ b_b(\lambda_3)]$ can be shown to be a constant independent of the choice of n for a given set of wavelengths. The SeaWiFS wavelengths, 443, 490, and 555 nm are fortuitously an excellent choice. From this observation we can formulate a ratio for the reflectance at three wavelengths, $R_{rs}(\lambda_2)^2 / [R_{rs}(\lambda_1)\ R_{rs}(\lambda_3)]$, that is independent of scattering and depends only on the ratio of the absorption coefficients. Based on this algorithm we show that within 4%, $R_{rs}(\lambda_2)^2 / [R_{rs}(\lambda_1)\ R_{rs}(\lambda_3)] = [a(\lambda_1)\ a(\lambda_3)] / a^2(\lambda_2)$, for the three SeaWiFS wavelengths. It thus is possible to define the relationship above entirely in terms of the absorption at 490 nm. This approach requires no knowledge of the highly variable scattering coefficients or their spectral dependencies, and thus is ideal for coastal situations.

Our participation in various research cruises over the last few years has led to the production of an extensive database of IOP and AOP. Using this database we have found that the spectral structure of the absorption and scattering coefficients are surprisingly regular (Barnard et. al., 1997). We are utilizing these spectral dependencies in formulating the backscattering independent algorithm for the determination of the absorption coefficient from the remotely sensed reflectance.

In support of our field program we have determined the temperature and salinity dependence of the absorption of pure fresh and seawater water so that observed variations in the natural environment due to these effects can be removed (Pegau, et. al., 1997). We have cooperated with instrument manufacturers and other scientific groups to convey lessons learned on various cruises that improve the instruments and the procedures for using them (Moore et al., 1996).

IMPACT/APPLICATIONS

The submitted inversion paper (Zaneveld and Pegau, 1997) has already led to radiative transfer studies of thin layers and may lead to the use of optical remote sensing to study the extent and depth of thin layers, fronts, and internal waves.

Our observation that the average cosine of the light field in the upper ocean does not behave as predicted by theory (Zaneveld, et. al., 1997) has led us to investigate non-traditional sources of light scattering such as turbulence, bubbles, and surface capillary waves (Bogucki, et. al., 1997; Flatau, et. al., 1997). Determining what circumstances these sources contribute significantly to radiative transfer is critical to any predictive IOP capabilities.

Analysis of the global data set showed that globally, there are linear relationships between the IOP at various wavelengths (Barnard, et. al., 1997). This is extremely important because it lends credibility to the global inversion of remotely sensed spectral radiance to obtain the spectral absorption. This is of particular application in the determination of IOP in inaccessible regions.

Finally we must understand the fundamental properties of pure fresh and saline water (Pegau, et. al., 1997) in order to accurately predict and measure the IOP.

TRANSITIONS

The instruments developed by WET Labs in cooperation with our group (ac-9, spectral in situ absorption and attenuation meter; SaFIRE, spectral in situ fluorescence meter) are widely used by the oceanographic community. They have greatly facilitated the study of the interrelationship of physical and optical properties in studies such as the CM&O ARI, COPE, LOE, and others. These instruments are also making possible IOP-based inversions using SeaWiFS and Aircraft Remote Sensing. The user group includes many of the SeaWiFS Science Group of investigators at NASA.

RELATED PROJECTS

- Coastal Mixing and Optics – We have participated in two cruises and are analyzing the measurements with the objective of understanding the dependence of the distribution of IOP on physical mixing and advective processes.

- Littoral Optics Experiment and Coastal Ocean Processes Experiment – We have participated in two cruises and are analyzing results to determine the relationship between physical, optical and biogeochemical processes in the near-shore environments.
- Coastal Benthic Optical Properties – We are developing a diver-operated spectral IOP device for the study of small-scale variations in the benthic environment.
- SIMBIOS – For this NASA funded project we are using our instrumentation to calibrate and validate properties measured by and derived from the SeaWiFS ocean color satellite.

REFERENCES

Barnard, A.H., W.S. Pegau, and J.R.V. Zaneveld, 1997, Comparison of inherent optical properties across a variety of oceanic regimes for application to remote sensing, ASLO meeting, Santa Fe (manuscript in preparation).

Bogucki, D., A.J. Domaradzki, J.R.V. Zaneveld, and D. Stramski, 1996, Light scattering by turbulent flow - Comparison with scattering on particles, *SPIE* Ocean Optics XIII, Halifax, Canada, S.G. Ackleson, R. Frouin, Eds., **2963**, 49-53.

Bogucki, D., A.J. Domaradzki, D. Stramski, and J.R.V. Zaneveld, 1997, Near-forward scattering on turbulence – Comparison with scattering on oceanic particles, Submitted to *Applied Optics*.

Flatau, P.J., M.K. Flatau, J.R.V. Zaneveld, and C.D. Mobley, 1997, Remote-sensing reflectance of bubble clouds in seawater, Submitted to *Journal of Geophysical Research* (*Oceans*).

Moore, C., E.J. Bruce, W.S. Pegau, and A.D. Weidemann, 1996, WET Labs ac-9: Field calibration protocol, deployment techniques, data processing, and design improvements, *SPIE* Ocean Optics XIII, Halifax, Canada, S.G. Ackleson, R. Frouin, Eds., **2963**, 725-730.

Pegau, W.S., D. Grey, and J.R.V. Zaneveld, 1997, Absorption and attenuation of visible near-infrared light in water: Dependence on temperature and salinity, *Applied Optics*, **36**, 6035-6046.

Zaneveld, J.R.V. and W.S. Pegau, 1997, A model for the reflectance of thin layers, fronts, and internal waves and its inversion, Submitted to *Oceanography*.

Zaneveld, J.R.V., W.S. Pegau, A.H. Barnard, J.L. Mueller, H. Maske, E. Valdez, R. Lara-Lara, and S. Alvarez-Borrego, 1996, Prediction of euphotic depths and diffuse attenuation coefficients from absorption profiles: A model based on comparison between vertical profiles of spectral absorption, spectral irradiance, and PAR, *SPIE* Ocean Optics XIII, Halifax, Canada, S.G. Ackleson, R. Frouin, Eds., **2963**, 585-590.

http://photon.oce.orst.edu/oomain.html